5 MEASURING AND MODELING NET CARBON SEQUESTRATION

5.1 MEASURING CARBON SEQUESTRATION LEVELS

Two significant issues pertaining to the measurement and modeling of carbon sequestration are: 1) How can net carbon sequestration and/or greenhouse gas emissions best be measured at an individual site, and 2) what are the most effective techniques to apply measurements to large areas? There are several challenges to accurately measuring the amount of carbon sequestered. First, the baseline carbon of existing sites must be measured in order to calculate the potential gains and losses from different land use activities. Second, measurements may be transferred into statewide or regional values. Third, baseline and changing carbon levels in other areas of the world (with a wide variety of soil types and land uses) must be accurately compared to the U.S. values. The year of 1990, which seems to be the accepted baseline year for which countries are to reduce greenhouse gas emissions, may be compared back to when measuring current or future sequestration. How stringent any future carbon sequestration markets are on utilizing a 1990 baseline year is not yet determined. For the purpose of this report, on-site and state-wide measurement and modeling will be the focus, where the third challenge is best dealt with on a national-scale.

From an economic viewpoint, the stored carbon must be measured in a readily understood and consistent manner so that potential buyers and sellers have a clear understanding of the product. A current method is to compare the amount of stored carbon in the soil, above- and below-ground biomass to one metric ton of atmospheric carbon dioxide that has been removed from the atmosphere or avoided from an emission source. Such a unit is commonly expressed in terms of a carbon emission reduction equivalent (CO_2e). Another major concern is the cost effectiveness and accuracy of the various measurement techniques that might be preferred for different management and accounting systems. For instance, would the per acre cost of estimating the carbon sequestered on one landowner's farm for an individual credit be different than the per acre cost of simply doing a county wide or statewide estimate. In each case this may depend upon the accuracy desired. The uncertainties associated with county-wide and state-wide estimates will likely be much larger, therefore may not be as marketable as credits.

On a statewide basis, one of the first items required is a baseline of current soil carbon levels. Because carbon can rapidly be lost from soils that have had conservation measures removed, accounting systems would also likely require an accurate accounting on the debit side of the ledger. At some point the amount of new or additional carbon sequestered may begin to decline as a soil reaches its capacity. Sequestration in the vegetation from conservation efforts such as agro-forestry will also need to be considered as well as emissions reductions from agricultural activities. There are several potential approaches to measuring the amount of carbon being stored from a particular land management practice. Generally these include:

1. Direct on-site measurements of soil carbon, biomass or carbon flux;
2. Indirect remote sensing techniques;
3. Default values for land/activity based practices.

Which method or methods are acceptable will depend upon the requirements of whatever accounting and management system is adopted. This in turn will depend partly upon the eventual stipulations in potential carbon markets and international agreements. The overriding question is how accurate an accounting of sequestration is needed and how expensive it is to conduct.

5.1.1 Direct on-site Measurements

Direct on-site methods include field sampling and laboratory measurements of total carbon in the soil and biomass. Changes in carbon content resulting from changes in land management may then be expressed as the change in carbon amount on an area or volume basis (biomass would require volume calculations, vertical height included with acreage). The calculation is not difficult but requires awareness of the variability of soil properties.

Another promising direct method is eddy covariance measurement of carbon dioxide fluxes. The vertical component of air movements (eddies) over a vegetated surface can be measured along with the carbon concentration associated with each eddy. By correlating vertical wind speed and carbon dioxide concentration for each upward and downward moving eddy, the net flux (uptake or release) of carbon dioxide by the ecosystem (vegetation plus soil) can be calculated. This method provides the net flux of carbon dioxide representative of a large area (landscape). The accuracy and precision of the eddy covariance method is improving as more experience is gained and is being used at about 150 locations worldwide.

There is some uncertainty of how accurately and efficiently a routine soil carbon field monitoring program can be implemented, but evidence suggests it can be done for a cost as low as a few dollars an acre, depending upon the degree of accuracy desired. Measurements may only need to be done once every 3 to 5 years, and in combination with satellite imagery and computer modeling could result in a more comprehensive assessment. There is still debate on the optimum frequency for sampling of soil carbon levels. In addition to scientific considerations that optimum frequency may depend in part upon the type of accounting required by potential future national or international programs or agreements. It may also depend in part upon market concerns for accuracy or risk. Long-term projects may be measured more accurately than short-term projects, due to the problems encountered with trying to measure changes in soil carbon within a few years, which soil carbon change is not linear.

Above-ground biomass may be easier to measure, where foresters have been measuring timber for years for wood production. These measurements, combined with biomass equations for a species of tree and shrub, can provide a fairly accurate estimate. Forestry and agroforestry measurements are discussed further below. Landowners themselves are capable of measuring tree dbh (diameter at breast height), where random trees can be sampled and with the species carbon default values, an average quantity of carbon stored can be estimated.

5.1.2 Indirect Remote Sensing Techniques

Even where field measurement programs could be developed, agricultural practices are inherently dispersed over a wide geographic area. Staffing costs for monitoring and verification of land use practices over such a wide area could prove to be cost prohibitive. Because direct field measurements can be expensive, the use of indirect remote sensing techniques is being considered. High altitude or satellite imagery has been used to verify no-till conservation practices, cropping patterns, and biomass accumulation. In addition to cost, remote sensing may have several other advantages. For example, remote based data can be used for verification and comparison of carbon storage on a regional basis, while an individual inspection may see only a single field. It is likely that a combination of field site visits may used as an audit means while utilizing a remote sensing program to estimate annual sequestration. Field operations may also provide records to assist in project implementation verification, used to compare with remotely sensed estimates. Remote sensing may not only be from high-altitude imagery, but from equipment ran across a field, sensing what carbon concentrations may be below the surface. Research is currently looking at soil conductivity and other factors to remotely estimate soil carbon levels, with accuracy.

5.1.3 Default Values for Activity Based Practices

Another approach to estimating carbon storage is the use of default values for certain land-based activities. A land-use based accounting system would focus on the changes in carbon stocks on managed lands during a defined time period. Default values would be assigned to a particular tract of land based upon county or regional level research on the average sequestration likely to result from specific agricultural or conservation measures in that area. Various values could be assigned to such broad land management activities as forest, cropland, or grazing management. Such an approach, termed a land use, land use change, forestry (LULUCF) system has several advantages. For example, under a LULUCF approach, field measurement of carbon storage changes in individual fields would not be necessary. Rather verification would only require monitoring that shows that a particular practice was used on the land in question. Land use monitoring can be readily measured by remote sensing techniques, eliminating the need for an army of field inspectors. Field plots may need to be set up, representing the average or a range of conditions of the entire project area, utilized as a reference to provide actual estimates, to increase the accuracy of large-scale project.

Biofuel use would simply be tracked by production and sales of ethanol and biodiesel. Where a number of gallons are produced and sold within the state, it can be assumed that a similar quantity of gasoline and diesel is not used, thus a reduction in emissions from the transportation sector. The amount of emissions related to the production of each gallon of ethanol and biodiesel would need subtracted from the estimated reduction of emissions from motor vehicles.

5.1.4 Measuring Forestry and Agroforestry Carbon

A distinct advantage of forest and agroforestry is the relative ease with which carbon accumulation can be measured and monitored. The baseline for agroforestry practices that involve tree planting could be assumed to be zero. Over time satellite imagery or aerial photos could be used to verify the continued presence and extent of a planting, such as a field windbreak. Statistical ground sampling methodology could be designed to document the amount of carbon accumulation over time for representative agroforestry practices across a range of site conditions.

The need for the development of biomass equations for trees and shrubs grown in agroforestry practices is still needed, however. Equations must be generated for a range of age, soil, and climate conditions. While biomass equations based on stem diameter and height already exist for most tree species, almost all of these equations have been generated from data gathered on forest grown trees. Some researchers estimate that equations underestimate biomass within windbreaks and other similar practices where the crowns of open grown trees and forest grown trees develop differently in response to light and available moisture regimes. For example, the lower branches of forest grown trees are shaded and in many species are self pruned. The stem tends to be long and straight with a relatively narrow crown structure. In contrast, open grown trees receive light from all sides and thus tend to have shorter, stockier stems and bigger crowns and numerous large, low branches.

For a further information on forest-based project monitoring, see http://www.winrock.org/REEP/Guidelines.html.

5.1.5 Modeling Soil Carbon

Numerous soil carbon models have been developed. Two of the more well known are the Century Model and the CQESTR model and are used as examples. There is an ongoing assessment of Nebraska soil carbon being conducted using the Century EcoSystem Soil Organic Matter Computer Model developed by the Colorado State University Natural Resources Ecology Laboratory and the USDA Agricultural Research Service. The model has provided reliable estimates of soil carbon changes and in the Nebraska case local data will be providing detailed inputs to the model. The model simulates dynamics of carbon, nitrogen, sulfur and phosphorous in the top 20 cm of the soil. Submodels simulate soil water balance, crop growth, dry matter production and yield. A variety of crop types and management options can be specified.

The CQESTR model developed by the USDA-ARS specifically shows the impact that different farm management practices have on soil carbon. Soil organic matter change is computed by CQESTR by maintaining a budget of soil carbon (1) additions as a result of sequestering atmospheric carbon dioxide in soil or adding amendments like manure and (2) losses of organic carbon through decomposition by microbes. The model requires the initial soil organic matter content for each soil layer of interest. The budget and identity for each organic input is maintained over a 4-year period of "composting." At the end of four years, the composted organic input loses its identity and is placed into the soil organic matter pool in an abrupt step function. Both the "composting" residues and the "mature" soil organic matter are decomposed daily using an exponential function driven by cumulative heat units with appropriate empirical coefficients for the type of residue, nitrogen content and incorporation into the soil by tillage. The model uses daily time steps to calculate heat units that are initiated for each organic input, typically after harvest of the crop. Other soil amendments are tracked similarly. When soil carbon is decomposed in soil to carbon dioxide, it is normally transported out of the soil in the gaseous phase by dispersion/diffusion and advection in air.

Another method that can provide valuable information to farmers the NRCS Soil Conditioning Index (SCI), which evaluates existing tillage and management practices, and gives an estimate increase or decrease of soil organic matter. The accuracy of the index is not adequate for carbon market use, but could be used to initiate carbon sequestration activities, providing farmers with an understanding of commitment to long-term soil conditioning.

Random soil sampling of fields will provide the most detailed and precise amount of carbon in soils. Soil survey information and soil reference sites may be most efficient, however, and provide adequate method of gross comparison of fields and regions. Looking at a 30 cm depth for example, its soil bulk density, and organic matter content, one can estimate a volume or weight of carbon on a per unit acre. One can assume that carbon is approximately 50% of the total organic matter content of soils, though it does vary with bulk density and other factors. For instance, a study in Amana, Iowa analyzed soil samples along a buffer strip and found that with a bulk density average of 38% of the organic matter, where organic matter averaged 3.5% within the top 33 cm. This study resulted in estimating soil carbon at 21.2 metric tons of organic matter per acre or 9.7 metric tons of carbon Of course, there other variables that may need to be looked at to improve these estimates.

5.1.6 Measuring Other Greenhouse gases

The basic approach used to measure other greenhouse gases such as methane and nitrous oxide is not dissimilar to the approach taken for carbon and carbon dioxide. Direct measurements of nitrous oxide emissions from cropland, and methane emissions from cattle and waste lagoons are collected and analyzed. Individual field measurements are then converted to equivalent tons of carbon dioxide emissions. (For example, methane has 21 times the global warming effect per metric ton of carbon dioxide and nitrous oxide has 310 times the effect. Therefore, one metric ton of methane equals 21 metric tones of equivalent reductions in carbon dioxide and nitrous oxide 310 times). The net reduction in carbon emissions resulting from changes in operations is then calculated. Although the reduction in methane and nitrous oxide emissions from specific agricultural activities emissions, such as reducing the amount of anhydrous ammonia used, covering waste lagoons, or using higher fiber cattle feed can be quantified, verification of these types of emission reductions can be difficult.

Changes in agricultural practices that reduce emissions are not easily verified by remote sensing techniques and may require on site observation. The actual amount of emission reduction achieved is often farm specific and development of default values for these types of activities on a statewide or regional basis is difficult. But field measurements are not easily obtained either. Research activities afford scientists the ability to compare a control to an alternative tillage scenario, where plots are measured with expensive testing equipment, while requiring some level of technician support. Farmers, as well as those potential buyers of emission offsets, are not likely to invest actual measurements, for likely such a small return. Research plots may be set up to compare practices and conditions initially and some time in the future to be used as a reference case to better estimate typical carbon sequestration rates for other similar project areas. Specific case studies for whole-farm analysis would be very beneficial in estimate net carbon and emissions benefits. This analysis would basically use an annual balance sheet to determine if the operation as a whole actually increases carbon sequestration above its farm related emissions.

5.1.7 Carbon Sequestration Verification for Carbon Markets

For a landowner to actually produce a carbon credit, which will likely consider the actual carbon sequestered and the emissions associated with the land use activities, a process that determines their baseline carbon and greenhouse gas emissions level is needed. There exist some methods used to verify an amount of carbon sequestered or reduced greenhouse gas emissions and may be acceptable to carbon market participants. Further work is needed, however, to better predict and measure a ‘whole-farm’ net credit. All sequestered carbon and greenhouse emissions relative to the land use activity will need to be calculated to determine a true credit, which is then potentially available for purchase.